CHAPTER 5: Operation Part 7 Natural Gas Burners [4 of 5]

4- The burner must be adjusted using instruments.

Natural gas combustion is not luminous, with a visible flame. Only the central part of the flame will be visible, appearing as a diffuse color, making it impossible to see where the combustion ends (the flame length).

The lack or excess of air is not easily observed by the color or shape of the flame. In reality, two combustion conditions occur: one with a dim, bluish glow (since the carbon and hydrogen ignite almost directly with the air mixture due to perfect mixing, an effect called hydroxylation),

And another, brighter, with a lighter, yellowish color, due to the decomposition of the gas upon entering a high-temperature zone, without having achieved perfect mixing with the air. This causes the gas to decompose into its hydrogen and carbon components or into other carbon and hydrogen components (an effect called cracking).

It is the carbon particles that produce the incandescent glow, combusting upon encountering oxygen or otherwise forming a deposit or soot particle if they come into contact with a cold surface (similar to liquid fuels).

This soot formation can be noticed as the chimney temperature rises. However, incomplete combustion can occur, not visible at the end of the flame. This can lead to the formation of imperceptible soot in the chimney flue gases (but when the accumulation is significant, its expulsion through the chimney becomes noticeable in patios and roofs).

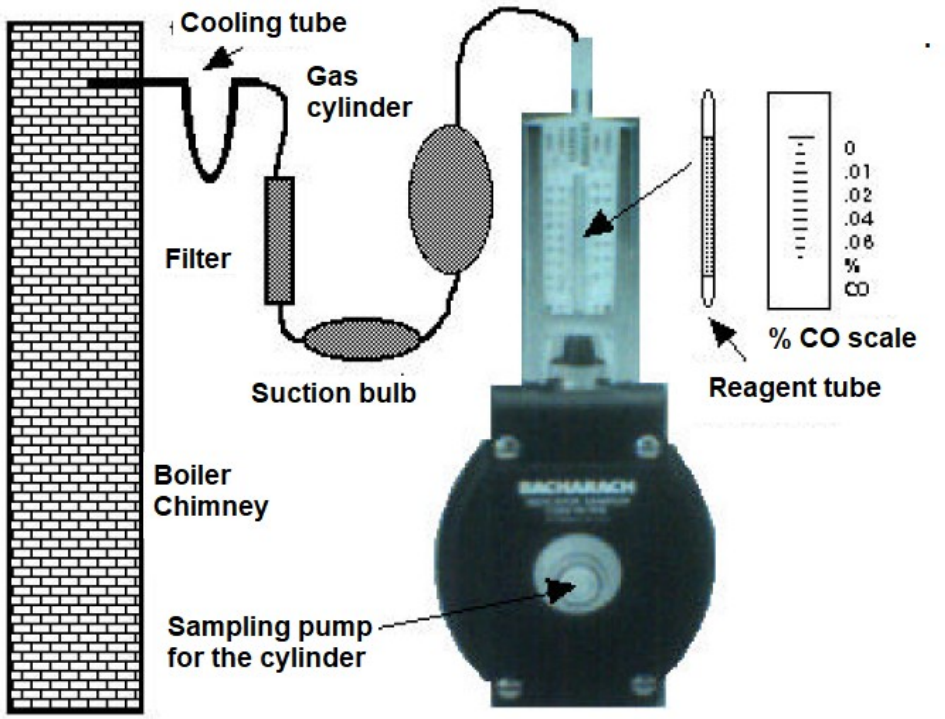
Generally, the combustion of natural gas does not produce "visible smoke" as in the burning of liquid fuels, that is: the lack or excess of air is not easily observed through the smoke, poor combustion (unburned products, from the gas itself to carbon monoxide, hydrogen or organic elements, some such as "pyroligneous" type acids, which are corrosive, in addition to being pollutants).

This means that when adjusting the excess air in a gas burner, it's generally necessary to use instruments that measure CO2 (carbon dioxide) or O2 (oxygen) in the flue gases.

It's also advisable to measure unburned gases or CO (carbon monoxide),

which should be at the minimum permissible level according to local regulations (generally less than 400 ppm of CO, or 0.04% CO). Otherwise, we risk being in an area with insufficient air and not being able to detect it visually.

INDICADOR DE MONOXIDO (MONOXOR BACHARACH)



As we have said, measuring carbon monoxide (CO) in gas combustion is very important, both to prevent air pollution and from an economic point of view (since if CO is present, it can be considered that there are twice as many losses from other "partially burned" volatiles, unless the instrument measures "unburned" gases and not just CO).

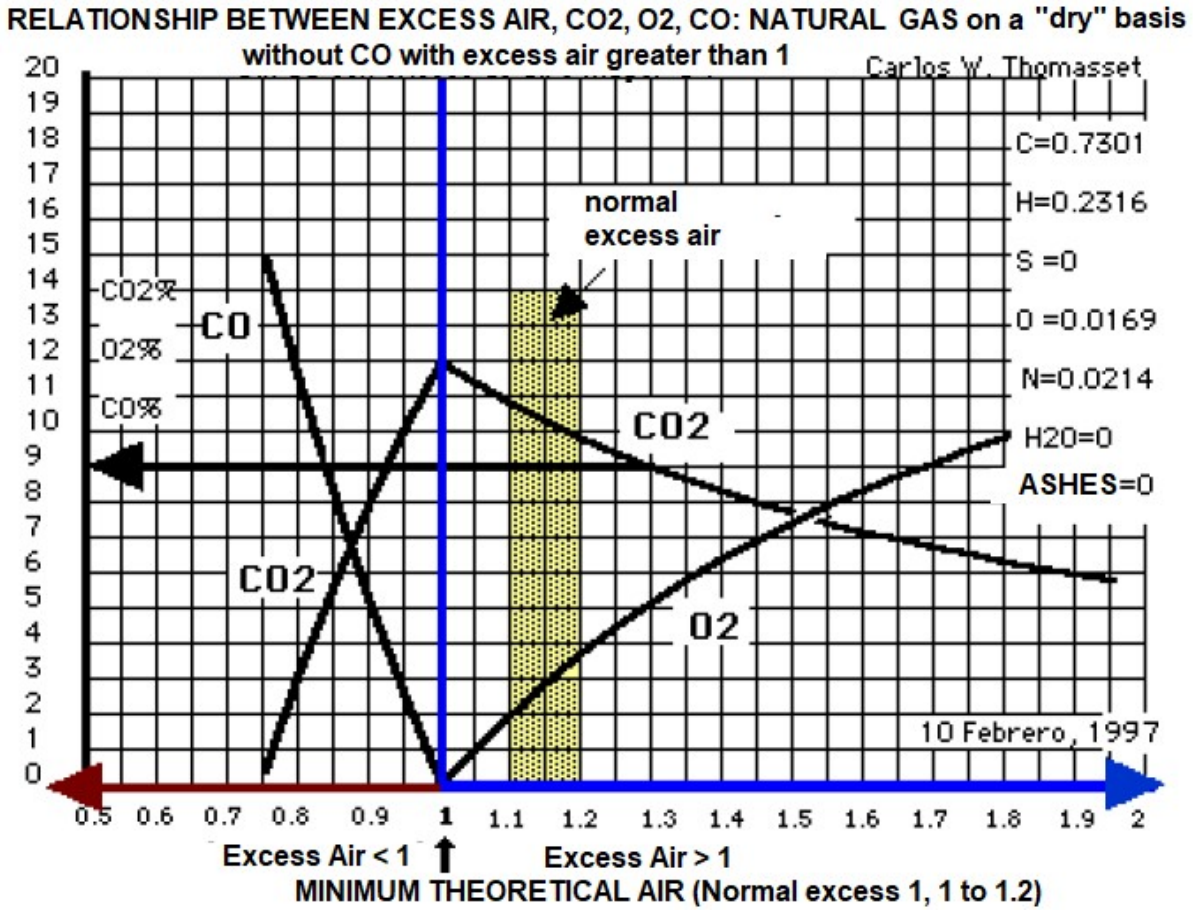
Since gas combustion does not produce smoke, it is important to take this measurement. There are several instruments to measure CO, it can be an **ORSAT** (which measures CO2, O2 and CO), it can be an electrical/electronic instrument or it can be a simple instrument like the **MONOXOR® from BACHARACH™** (its manufacture is discontinued [year 2001], but these devices are still in use).

The MONOXOR® for measuring CO is based on passing a measured amount of flue gas, which is previously stored in a rubber balloon (which is filled with flue gas through a cooler and a filter, propelled with a rubber bulb that acts as a pump). This gas from the cylinder, measured by a volume-

calibrated pump, is passed through a small tube filled with a yellow, sandy substance. When a certain amount of gas is drawn in by a pump from the Monoxor® itself, if the gas contains CO, the yellow color changes to a dark color.

The longer the color change in the tube will be, the greater the percentage of CO_2. A scale will indicate the percentage of CO_2 (after one use, if the tube hasn't darkened more than halfway, it can be inverted and used again). Its manufacture has been discontinued by BACHARACH™.

Generally, when burning gas, the CO content should not exceed 0.04% (400 ppm). See the following graph. While the maximum CO2 values in gases are lower than those in liquid fuels (due to a higher hydrogen-to-carbon ratio), if we only measure CO2 or O2, **we risk being in an area of poor air quality and having a quantity of unburned gases that are not visible due to the flame color or the smoke in the chimney.** This is not only polluting, it's also a potentially significant economic loss; furthermore, these flue gases can be highly corrosive. See this theoretical combustion diagram:



This means that for the same CO2 measurement, we can be in an area of excess air or lack of air.

However, if we also measure oxygen and there is an excess, it doesn't necessarily mean that this corresponds to an actual excess of air, since there could be excess oxygen due to "incomplete combustion" (whether due to a poor mixture of air and gas, excessive flame cooling, or insufficient combustion time in the combustion chamber).

This situation doesn't appear in this diagram, but it does appear in the Ostwald triangle, which I recommend using to study combustion problems.

To calculate excess air, a mathematical formula is generally used that involves CO2, O2, and CO. This way, regardless of the fuel composition, the calculation will yield the excess air.

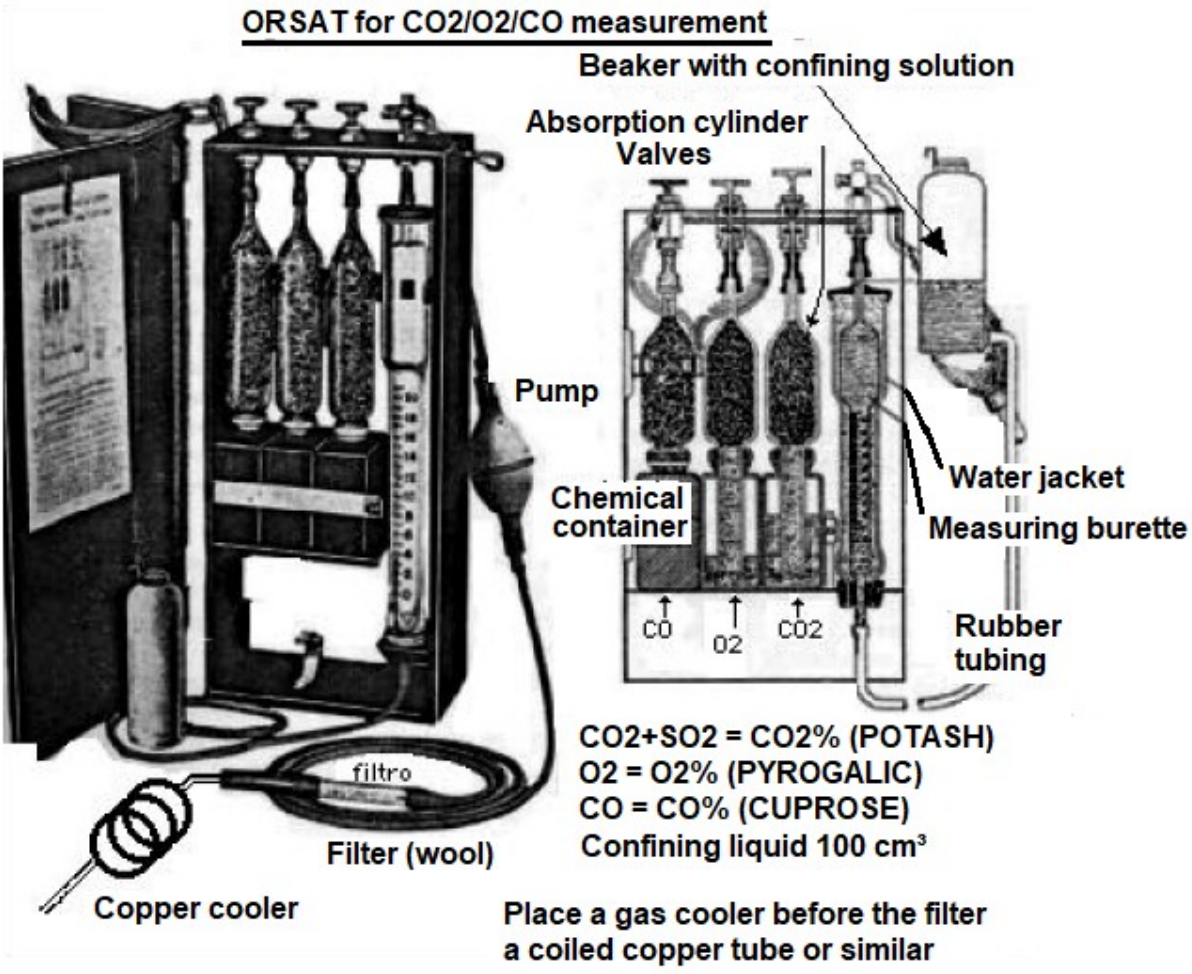
All these chemical measurement devices (Fyrite®, Mono, ORSAT, etc.) use a dry basis. The CO2 measurement also includes the presence of SO2 (sulfur dioxide), which volumetrically responds in the same ratio as CO2 to oxygen (for calculating excess air).

That is, we take it as CO2 when in reality it is a mixture of CO2 + SO2 (the incidence of SO2 is very low in the variation of the % reading of excess air when taking it into account as CO2, given the relatively low sulfur content of fuels compared to carbon).

THE ORSAT SET

The ORSAT is a very "old" device, but still useful for measuring combustion gases. While its measurement isn't highly precise, its reading is relatively reliable when **used in conjunction with an Ostwald triangle**.

Its operation is based on taking a pre-cooled sample through a wool filter, drawn in by a rubber pump (of the "barber's" type). The sample is then pushed through a 100 cm³ graduated measuring burette (which is submerged in another container filled with water to maintain a stable sample temperature).



The propelled gas is then forced out through a beaker filled with a "confinement liquid" (a liquid that does not absorb the gases and allows us to raise or lower the beaker to push or draw the gas through the different absorption liquids).

Once enough flue gas had passed through the measuring burette (as if washing with gases to ensure its original constitution), we maneuvered the inlet and exhaust valves to the atmosphere, so that with the beaker we leveled the zero (0 equivalent to 100 cm3 of sample, leveling the surface of the confining liquid in the burette and in the beaker to the same level, so as not to compress or expand the gas sample) of the burette.

Before performing this maneuver to "capture" 100 cm3 of gas, we must level all the absorption liquids in each absorption chamber (where the fillings are, glass tubes or copper chips or wires, which are soaked in the absorption liquid to be able to selectively absorb each gas; it is filled to the mark it has on the thinnest neck).

Next, we will push the gas so that it enters completely into the first absorption chamber (to absorb CO2 and SO2, carbon dioxide and sulfur dioxide, which is absorbed by a strong potassium hydroxide solution). We repeat the process of pushing and returning the gas to the measuring burette as many times as necessary to ensure a constant reading.

We must take care to return the absorbent liquid to the same mark in its container, as each absorption chamber discharges the liquid into a container sealed from the atmosphere by a balloon to prevent contact with the air. The absorbent liquid contains approximately 100 cm^3.

Then, with the constant reading, the reading of each 1 cm3 or 1 ml will be the % of CO2% (to make this reading, level the burette and the beaker, taking care that the effect of the "menisci" of the confining liquid in both are equal).

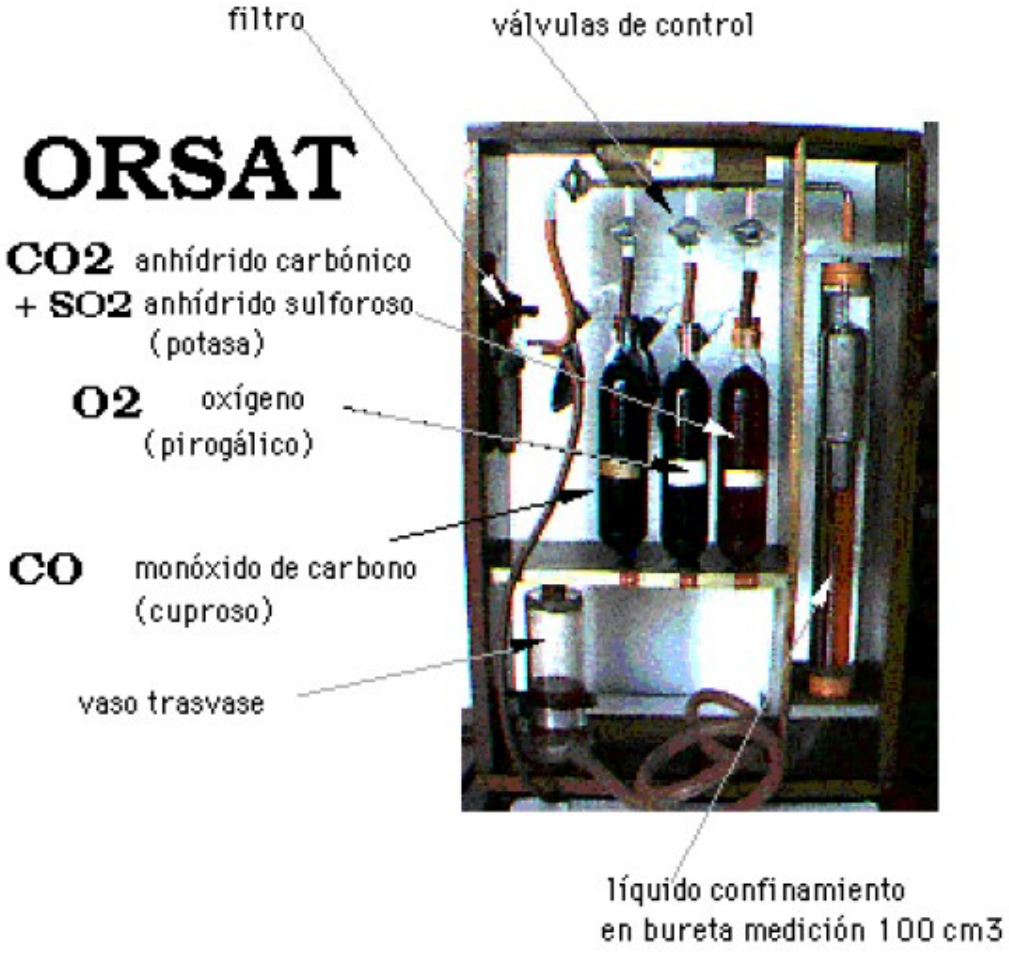
Here the remaining gas will be less than 100 cm^3 (since it loses CO_2 and SO_2, it could also lose some acid gases, but it is all taken as CO_2 given the low influence of SO_2 and acid gases on the percentage). The reading will be on a dry basis (dry gases).

Now we will absorb the O_2 (using pyrogallic acid, a wood derivative, as the absorbent. This acid must not be in contact with the atmosphere, otherwise it loses effectiveness due to the presence of atmospheric O_2).

Once the O2 is absorbed, the burette reading will be the difference between the CO2 + SO2 + O2 concentration and the previous CO2% (+SO2) reading. Next, we will absorb the CO (using a cuprous chloride solution).

The reading for this measurement will be the CO2 + SO2 + O2 + CO concentration, so the CO% will be this reading minus the previous one.

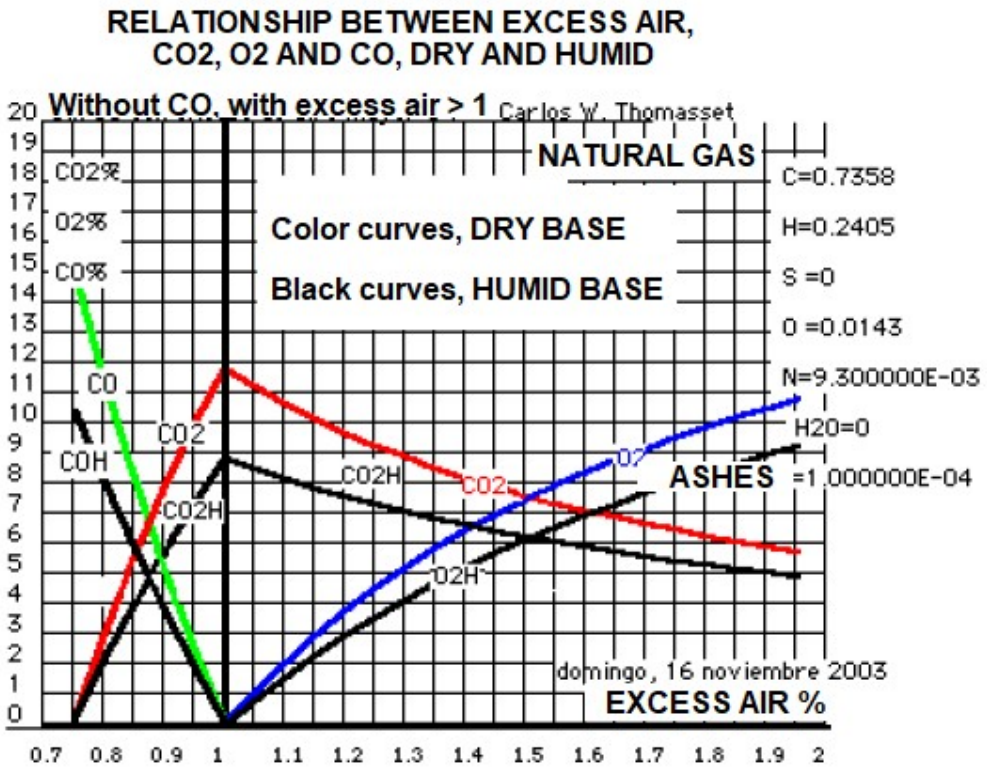
Absorption liquids should be prepared as absorption problems are observed (the maneuver must be repeated many times to absorb, since the color and viscosity give an idea that there is a change in them, especially in pyrogallic and cuprous, taking into account that cuprous is poisonous).



Then, for better use and interpretation of ORSAT, it is advisable to use an OSTWALD diagram, since although we can know the excess air by means of a formula in which the 3 measured elements (CO2%, O2% and CO%, see below a formula to calculate the excess air with incomplete combustion, in which CO2, O2, CO participate, in dry ratio) without needing to know the composition of the fuel, which is necessary to draw the OSTWALD triangle

(do not forget that the OSTWALD triangle is the ratio of the combustion gases in dry ratio, that is, with the condensed water vapor).

$$\&(ex.aire)=\frac{(1-CO2-O2-CO)}{(1-CO2-1,5\,CO-((O2-0,5\,CO)/0,21))}$$



Observe in the graph above the difference between the percentage ratio of flue gases on a "dry" basis and on a "wet" basis (CO2H, O2H, COH) for natural gas (i.e., as found in the chimney and not as found after being drawn into a device that cools and condenses all or part of the combustion water and moisture from the fuel and combustion air).

Instruments that reflect measurements on a "wet" basis are the most common: zirconium oxide cells (which operate inside the chimney at high temperatures), or other instruments that operate at high temperatures that prevent condensation.

Instruments that bring the gases to the ambient temperature of the measuring device and are not "absorption" instruments, such as the Fyrite® and the ORSAT, provide gas ratios with such a low percentage of humidity

that their value is practically on a dry basis. Furthermore, if greater accuracy is desired, a correction for temperature under the measurement conditions must be made.

THE OSTWALD TRIANGLE IN NATURAL GAS UTILIZATION

To facilitate burner adjustments, the OSTWALD triangle can be used. This triangle represents a dry-basis gas ratio (meaning that the moisture content—water from combustion and moisture from the air and gas—present in the combustion gases is assumed to be condensed).

It is a graph that relates these same values, but each curve on the graph is plotted for only one type of fuel, as it corresponds to the specific composition of each fuel.

The vertical lines represent the CO2% by volume values (CO2 + SO2), and the horizontal line represents the percentage of oxygen (with the maximum O2 for air being 21% by volume).

Starting from the maximum CO2%, that is, the point where the air used is at its "minimum" or "stoichiometric" level—neither excess nor insufficient air—which in natural gas is approximately 12% (the point where all the oxygen is consumed, i.e., 0%), a line is drawn connecting to the maximum oxygen point (21% O2 and 0% CO2, i.e., no gases or infinite excess air).

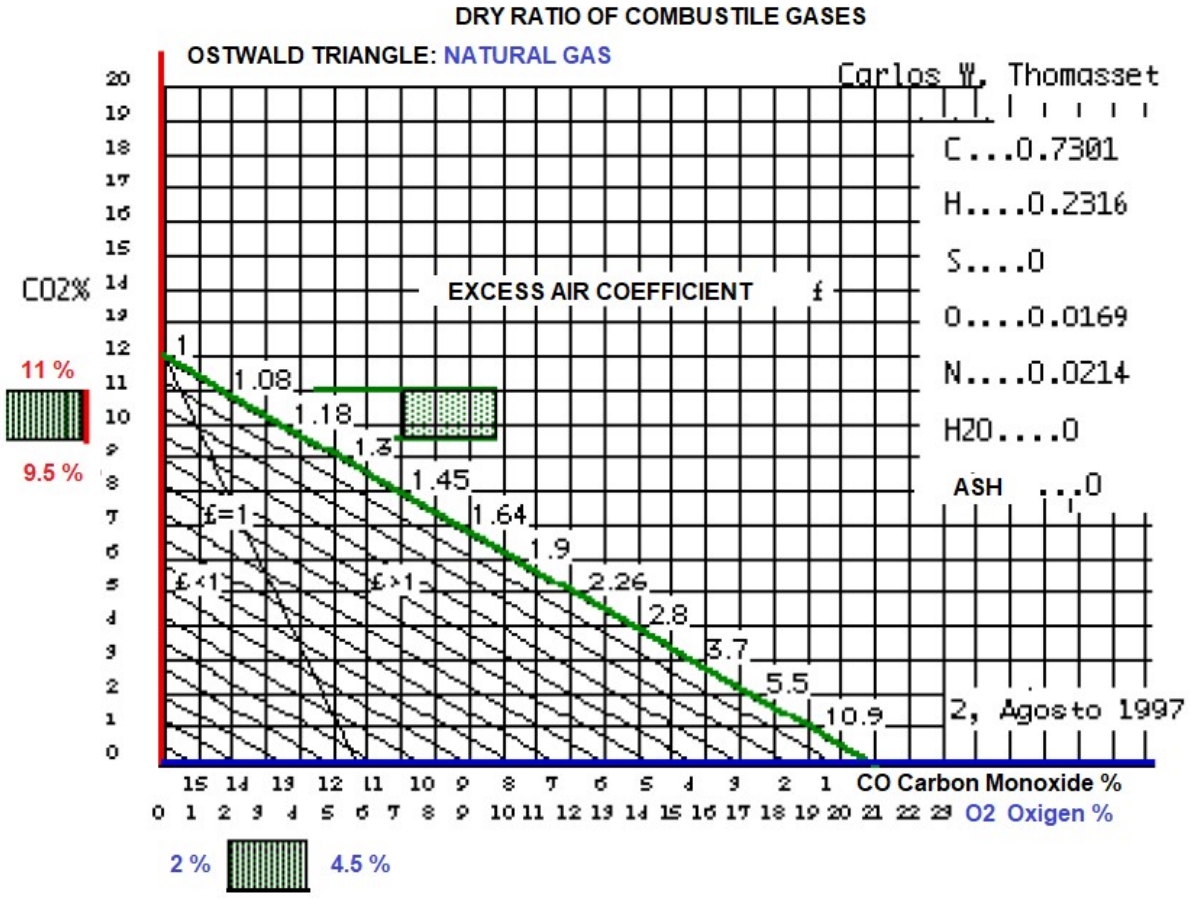
On this line will be the values for excess air with complete combustion (with CO equal to 0%). Parallel to this line will be the increasing CO% values, with the maximum CO occurring at the intersection of CO2 equal to 0% and oxygen equal to 0%, which in this case will be 15.5%.

This Ostwald triangle was drawn based on the average composition of natural gas. Accordingly, when adjusting a natural gas burner, CO2 or O2 should be measured, in addition to unburned gases or CO (carbon monoxide). For this, we can use independent meters or an ORSAT.

The ORSAT measures CO2 (plus SO2), O2, and CO by chemical absorption. Based on these three measurements, we can use the Ostwald triangle to understand what is happening with the burner or mathematically calculate the excess air.

The ORSAT is an instrument that has been widely used for many years, and while it is not highly precise, it is very useful, and in a country like ours, its use is still very convenient. (Modern electronic equipment, much of it

computerized, requires periodic and costly calibrations, detector replacements, and firmware, software, and operating system updates, which makes them impractical.)



THE OSTWALD TRIANGLE IN MORE DETAIL

This chart, a visual system for viewing the combustion results, is plotted as a percentage of dry gas volume and is used as follows:

It is a triangle formed by the vertical leg (ordinate) representing the CO2% of each particular fuel (each triangle is only valid for each fuel, since its shape corresponds to the chemical composition of the fuel and the Earth's atmosphere at sea level, and with dry gases), in which the CO2% corresponds to the sum of CO2% + SO2% (since both elements require the same volume or molarity of oxygen, and since the absorption instruments will absorb both, and the incidence of SO2%, sulfur dioxide, is generally low), meaning that the maximum value will be the maximum CO2% of the fuel (the sum of CO2% + SO2%, when the air required corresponds to the minimum or stoichiometric amount, with complete combustion).

This maximum CO2% will be higher as the hydrogen/carbon ratio decreases (H/C), meaning the fuel has more carbon in relation to hydrogen (we can order fuels from highest to lowest hydrogen content: generally natural gases, light liquid fuels contain more hydrogen, and heavy liquid fuels, such as fuel oil, and generally solid fuels such as firewood, lignite, and coal in general, have higher carbon content).

On the horizontal leg (abscissa), the percentage of O2 (atmospheric oxygen, approximately 21% by volume) is plotted up to 21%.

The hypotenuse will be the point of intersection of complete combustion, where the values corresponding to each specific CO2% and O2% value intersect. This indicates the point starting from 0% excess (minimum or stoichiometric air, expressed as £=1, meaning there is no excess O2, it is 0%, and CO2% is at its maximum), passing through all values up to infinite excess air (£= ∞), when O2% is 21% or at its maximum, a value that only occurs in reality when there is no combustion.

Parallel to the hypotenuse, the values for each percentage of CO (carbon monoxide) are plotted, with the maximum CO occurring when both CO2% and O2% are 0. This maximum CO value is different for each fuel, as is the CO2% value. The value is higher as the hydrogen/carbon ratio (H/C) decreases; that is, the more carbon the fuel contains, the higher the value (highest in coal and cellulose fuels, decreasing slightly in fuel oil, decreasing slightly as liquid fuels have lower density, and decreasing even further in organic gases, such as natural gas, etc.).

When the CO2% and O2% measurements do not coincide on the hypotenuse (complete combustion), the point of intersection will be in an area of incomplete combustion, meaning there is a percentage of CO present. Generally, the readings do not close at a point, but in a triangle (whose vertices will be CO2-O2, CO2-CO and O2-CO), in this case the center of gravity of the triangle will be taken as the point, that is, the intersection of the perpendicular bisectors of the sides.

To determine the excess air (£) corresponding to a given point, we must first draw a line indicating the points where excess air £ = 1 (excess air equal to 1, minimum air, or stoichiometric air, meaning there is neither too much nor too little air).

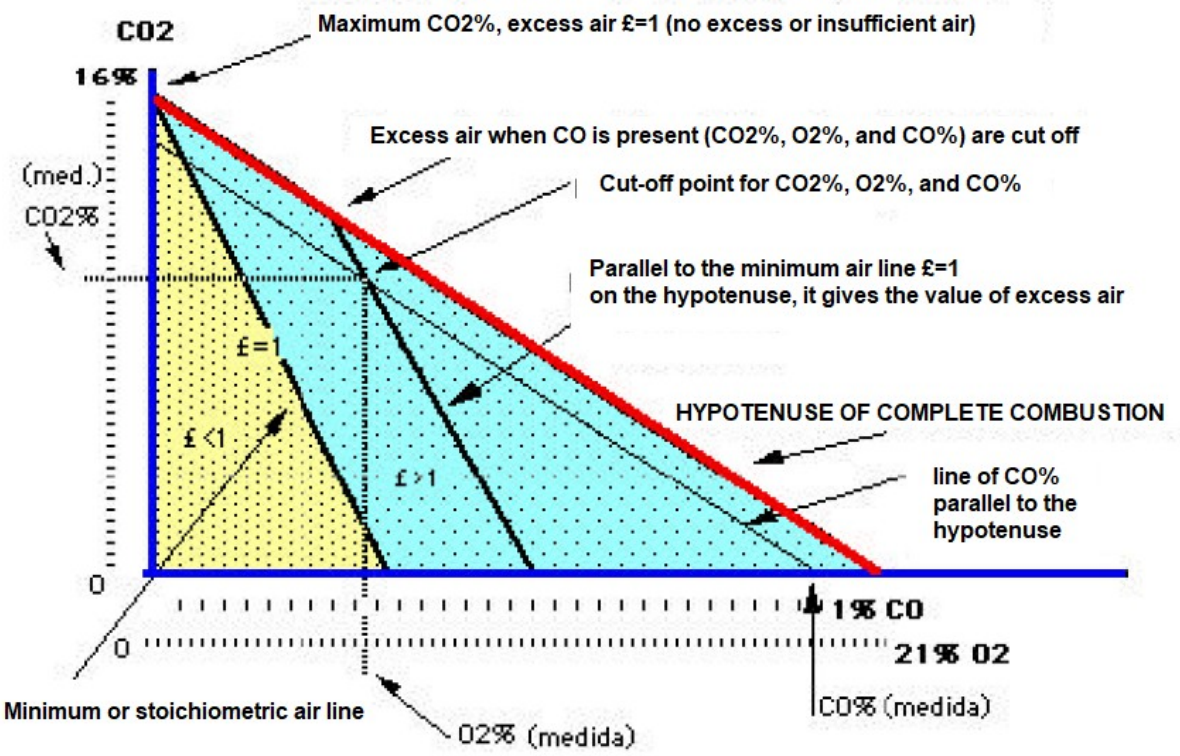
This line passes through the point of intersection of maximum CO2% and O2% = 0, with the other point being the O2% corresponding to CO2% = 0

when the air is at its minimum (stoichiometric).

Once this line is drawn, the triangle will be divided into 3 zones: a - the zone with the lowest x-value, where there is a lack of air (£<1); b - on the line, where there is minimum air (£=1); c - on the O2% values above the line (£>1), where there is excess air (too much air).

Starting with lines parallel to this line, on the right side or where there is excess air, the intersection of these lines with the hypotenuse will give the corresponding excess air at the point inside the triangle.

As can be seen, this triangle represents all the possibilities for combustion (although a "corrected" triangle can be drawn for the CO% values, since it has been detected that when CO is present, there are also unburned combustible gases such as hydrogen; however, we consider these theoretical triangles sufficient for practical purposes, as the desired result should be complete combustion).



The previous sketch indicates the most important parameters in the Ostwald triangle. Remember that to the right of the line of minimum or stoichiometric air (£=1), there will be excess air.

If CO is present when measuring, it is not due to a lack of air, but rather to

incomplete combustion. The CO2% and O2% values will fall in the area Σ>1 (excess air greater than £1). If we measure CO%, it will give a value that increases from the hypotenuse towards the interior of the triangle, with the highest CO% value being the point of intersection where CO2% and O2% are equal to zero (0%).

This maximum CO% value will be higher in fuels with a lower H/C ratio (less hydrogen than carbon).